Optical Dynamics in the Adriatic Sea: Production, Transformation and Transport of Optical Properties from the Coastal Zone into the Open Ocean

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LONG-TERM GOALS

The fundamental goals of this research are to understand the coupling of the optical dynamics of the ocean with physical forcing in both coastal and open ocean environments. We specifically want to better understand these processes by:

- Examining the interaction between physical and bio-optical responses of the upper ocean to atmospheric forcing.
- Observing the details of bio-optical influences of instabilities, secondary circulations and vertical motions associated with upper ocean fronts.
- Examining the role of river inputs into the coastal zone on the dissolved and particulate components that contribute to the optical properties on the continental shelf.
- Studying the exchange between the continental shelf and open ocean through cross-shelf transport processes including filament-related processes that have been observed in coastal regions throughout the world.
- Providing statistically meaningful spatial mapping of optical parameters for ground truthing of optical remote sensors.

OBJECTIVES

The objectives of this effort are to examine:

- The transitions of inherent optical properties across coastal/open ocean boundaries and their effect on apparent optical characteristics of the water column.
- The role of physical processes (river inflow, upwelling, coastal filaments, and frontal processes) in the production, distribution and flux of optical properties between the coastal and the offshore zones.
- The relationship between the surface expression of three-dimensional ocean processes and the interior processes.

APPROACH

Three primary observational approaches have been used in this effort. A hybrid Seasoar/Triaxus (TRISOARUS) towed undulating vehicle (TUV) was equipped with a Wetlabs AC-9 multiple wavelength attenuation/absorption meter, as well as a transmissometer and chlorophyll and CDOM

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fluorometers for three-dimensional mapping of the optical properties across the shelf/open ocean boundary and frontal regions in the Adriatic Sea (Figure 1). In the mapping mode, a Satlantic Micro-SAS remote sensing radiometer system was used to provide continuous measurements of remote sensing reflectance. These observations are compared with the in situ measurements of inherent optical properties. We also employ more traditional station mode sampling where optical properties are profiled with a Bio-Optical Profiling package that includes two AC-9 absorption [a]/attenuation [c] meters, one Hydroscat-6 optical backscatter sensor, Satlantic radiometers for measuring downwelling irradiance and upwelling radiance at 7 wavelengths, and a CTD equipped with a transmissometer, chlorophyll fluorometer, and CDOM fluorometer.

WORK COMPLETED

The initial phase our effort was to mount the optical sensors on the new Trisoarus tow vehicle. This work was accomplished by the Dr. Craig Lee's group at the Applied Physics Laboratory, University of Washington. The resulting vehicle configuration is shown in Figure 1.

Figure 1. Pictures of the APL/UW Trisoarus tow vehicle equipped with standard CTD sensors as well as with the USC WetLabs AC-9 for measuring inherent optical properties. Other sensors are within the body of the vehicle. The picture on the left shows the vehicle on the deck of the ship prior to deployment, and the picture on the right shows the vehicle being deployed in the Adriatic sea..

Two field efforts in the northern Adriatic have been completed. The first cruise in February 2003 was intended to study the role of strong atmospheric forcing on the ocean and to resolve the structure and response of the upper ocean to this forcing. During this effort four regions were focused on: the mid-Adriatic filament near Sibenik, Croatia, the Istrien front south of Istria, the Po River plume immediately off of the mouth of the river, and the Po River plume front downcoast from the mouth of the river. The second cruise occurred in May-June 2003 and was intended to examine the role of physical forcing due to both atmospheric processes and the spring freshet from the Po River, and the bio-optical response to these forcing processes.

RESULTS

The winter cruise occurred during a period when there were frequent Bora wind events. During one of these events we were able to capture the evolution of a front south of the Istrian Peninsula. With the

tow vehicle we were able to resolve horizontal distances of 200 meters providing very high horizontal resolution of the frontal region. During the event the water column was well mixed on either side of the front (Figure 2). As the front evolved and the winds relaxed the front propagated northward and water from the northern side of the front was overlaid with water from the southern side of the front creating a stratified water column where it had been previously vertically mixed. In this particular event the inherent optical variables were closely coupled with the physical variables. Attenutation at 650 nm correlates with both absorption and attenuation at all wavelengths, and its variability parallels the variability of temperature very closely.

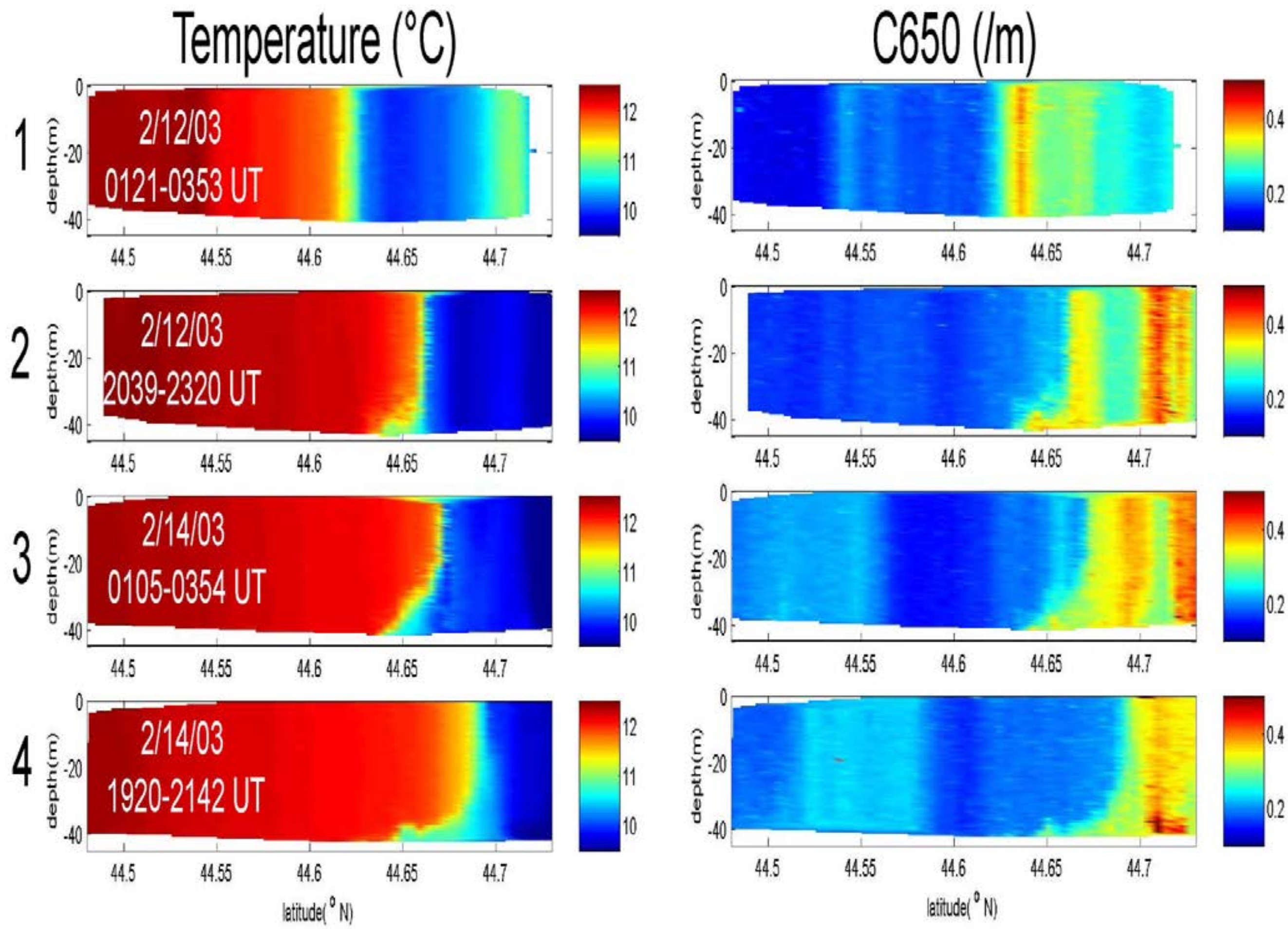

Figure 2. Cross-frontal section of the Istrian Front during a Bora event in mid-February 2003. This section was the second of 6 lines in an approximately 34 km x 34 km grid pattern. Attenuation at 650 nm (C650) is representative the bulk of the inherent optical properties because the particles were primarily inorganic, perhaps from a terrigenous source. Horizontal resolution was approximately 200 meters at mid-depth.

In contrast to the strong vertical mixing and frontal structure found in winter, the eastern and central northern Adriatic is strongly stratified and a subsurface chlorophyll maximum becomes the major source of mid-water column optical variability in spring and early summer. However, the Po River plume provides a significant input of dissolved organic material, inorganic nutrients, suspended

particulate material and buoyancy in both winter and summer. The impact of the plume on the coastal ocean immediately seaward from the river mouth is shown in Figure 3. The plume is clearly indicated by salinity showing a low salinity feature extending a signficant distant eastward from the river mouth. The attenuation at 650 nm (c_{650}) indicates that there are significant particle concentrations in the low salinity part of the plume and also near the bottom throughout the sampling region. Chloropohyll bearing particulate material is clearly confined to the nearsurface region within the plume and not apparent at nearbottom except farther offshore and outside of the river plume. Dissolved organic matter is high at the surface in the portion of the plume nearest to shore, but in the offshore region the nearsurface CDOM decreases and the maximum is deeper in the water column, probably due to photo-bleaching of the CDOM nearsurface. The structure of the plume is complex. A tongue of higher particulate and CDOM extends downward from the surface nearest to shore. The nearbottom suspended particulate signhal is not necessarily correlated with the presence of the plume directly overhead.

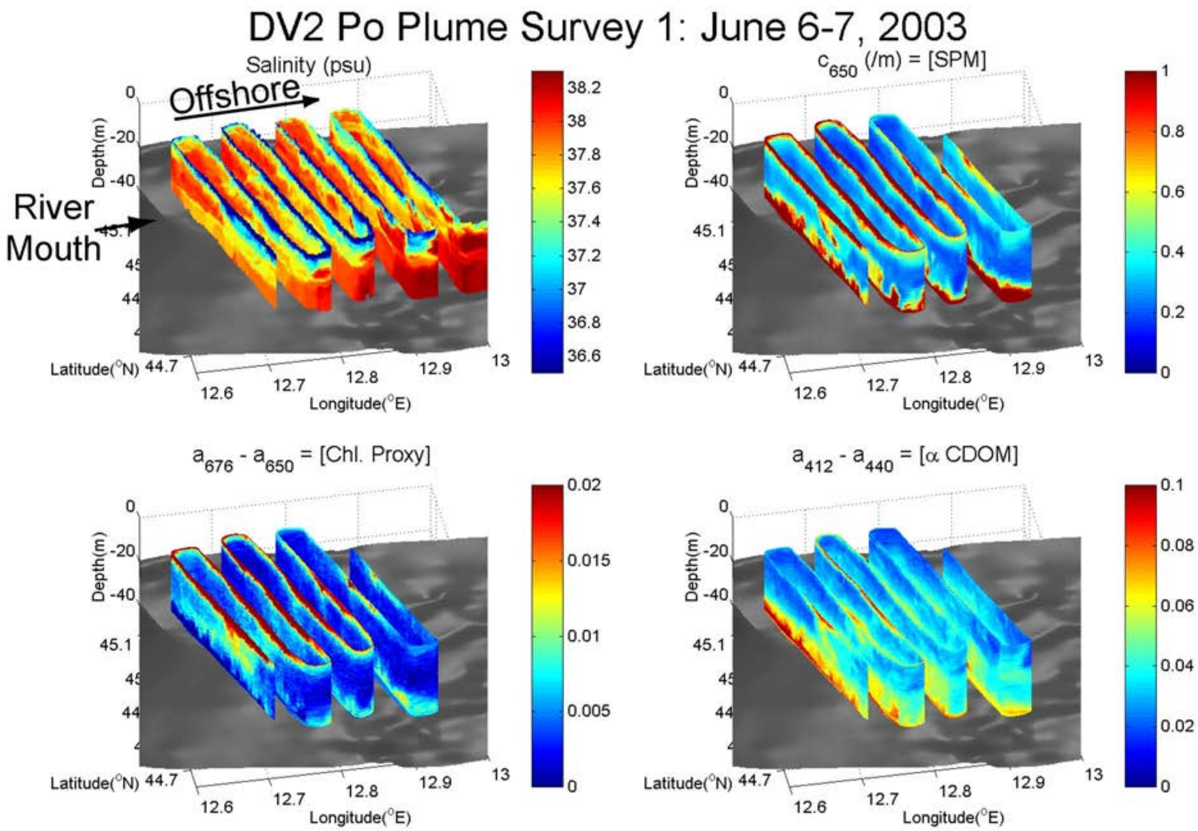

Figure 3. Curtain plot of salinity and optical variables derived from the Trisoarus survey of the Po River plume on June 6-7, 2003. The gray area indicates the bottom. The top left panel shows salinity; the top right panel is C_{650} indicative of suspended particulate concentration; the lower left panel is the difference between a_{676} and a_{650} (proportional to chlorophyll concentration); and the bottom right panel is the difference between a_{412} and a_{440} (proportional to CDOM concentration).

IMPACT/APPLICATIONS

Mapping of inherent optical properties from a towed vehicle provides detailed descriptions of the optical properties in relational to the physical properties of the water column and the processes that force the observed distributions. This enables us to examine the complex three-dimensional variability that is present and the evolution of this structure in time. The coupling of these in situ observations with remote sensing observations provides a foundation for interpreting ocean color patterns observed from space with the complex in situ processes that are occurring in the ocean. Such variability is difficult to observe from other platforms at this time. We expect that these observations will be important in the validation of inverse modeling procedures where in situ optical parameters are estimated from remotely sensed observations.

RELATED PROJECTS

Our effort is closely integrated with several other efforts that are part of the "Dolce Vita" study of the northern Adriatic Sea. Our work closely integrates with the effort of Dr. Craig Lee (Adriatic Circulation Experiment – Mesoscale Dynamics and Response to Strong Atmospheric Forcing; http://www.apl.washington.edu/projects/adriatic_sea/summary.html). Our measurements are taken simultaneously and provide a direct coupling between the physical and bio-optical processes.

Dr. Robert Arnone, NRLSSC is responsible for remote sensing observations (Satellite Characterization of Bio-Optical and Thermal Variability in the Adriatic Sea; http://web7240.nrlssc.navy.mil/). The coupling between remote sensing and in situ optical properties is of fundamental mutual interests.

Simultaneous with our in situ mapping of inherent optical properties both optical and non-optical drifters were deployed by Pierre Poulain and Elena Mauri (Dynamics of Localized Currents and Eddy Variability in the Adriatic; http://doga.ogs.trieste.it/doga/sire/dolcevita/index.html).

Other efforts that are part of this project include the following:

Dr. Clive Dorman, Nearsurface meteorological observations in the northern Adriatic.

Dr. Hartmut Peters, Vertical convection and turbulent mixing in the Adriatic Sea. (http://www.rsmas.miami.edu/divs/mpo/people/hpeters.html)